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Crystallographic orientation study of spray formed hypereutectic Al-Si alloys used in the automotive industry

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Abstract

Aluminium-silicon hypereutectic alloys have a wide acceptance in the automobile, electric and aerospace industries. This is due to the high strength to weight ratio, the low coefficient of thermal expansion and good resistance to wear and tear. A narrow range of possible compositions limits the use of conventional ingot metallurgy for the obtention of these alloys. This can be attributed to the formation and presence of coarse silicon particles, because of the low cooling rates associated to ingot metallurgy. The use of spray forming can overcome this hindrance. The present work is a microstructural and X-ray diffraction study of two spray formed Al-Si alloys, already in commercial use.

Introduction

Some Al-Si alloys have characteristics such as good wear resistance, low coefficient of thermal expansion combined with a high strength to weight ratio. Due to such properties, these alloys have been used in several applications from the automotive to aerospace and power industries [1-4]. The outstanding wear resistance is due to the high volumetric fraction of silicon phase and intermetallics. Applications of the Al-Si alloys in the automotive industry, include engine blocks and parts of engines, particularly, cylinder liners. The main advantages of the use of these alloys are weight reduction, low fuel consumption and less emission of pollutants [1,2].

The use of engine blocks made of hypereutectic aluminium alloys has been considered by many world manufacturers. Blocks of the Al17Si4CuMg alloy are very difficult to cast. They have been produced by expensive processes, such as chill mould casting at low pressure. This process was necessary to obtain refined silicon particles used in the contact area between the cylinder and the piston rings. The conventional die cast Al9Si3Cu alloy has been preferred due to economic reasons. However, the tribological properties of the late alloy do not favour its use in the combustion chamber area. The accepted solution is to use cylinder liners made of cast irons; cast or spray formed high silicon aluminium alloys, composites or coatings in

this area [2].
Hypereutectic alloys can be produced by ingot metallurgy [1,2] or by rapid solidification processes, such as: melt spinning [4], atomisation [4,5] and spray forming [4-9]. The use of ingot metallurgy for the production of these alloys is limited by the range of possible chemical compositions. That can be attributed to the formation of eutectic phases and coarse primary silicon phase, due to the low cooling rates associated to the ingot metallurgy. The distribution of coarse silicon particles in the alloy leads to low ductility and limited workability of the hypereutectic Al-Si alloys. Many of the problems associated with ingot metallurgy can be overcome by rapid solidification techniques. The main advantage of the use of the rapid solidification process is the significant modification of size, morphology and distribution of the primary silicon phase in the matrix, comparatively to the conventional process. This has been achieved by spray forming hypereutectic Al-Si alloys or co-depositing Si particles.
The technology for producing cylinder liners by casting iron and spray forming aluminium alloys is well established. The use of aluminium alloys for such application was made possible by the admixture of large amounts of alloying elements that precipitate as hard second phase particles. The use of such alloys with hard particles is viable if these particles are finely dispersed, allowing further mechanical working. In this work is undertaken a microstructural X-ray diffraction study of two spray formed hypereutectic aluminium-silicon alloys taken from commercial cylinder liners.

Experimental

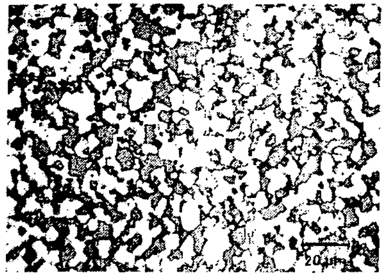
Spray formed hypereutectic Al-Si alloy specimens were taken from two cylinder liners, supplied by different manufacturers, after use in internal combustion engines. In this work, the specimens were called: alloy 1 and alloy 2. These specimens were analysed by optical (OM) and scanning electron microscopy (SEM), and by X-ray diffraction. Properly prepared metalographic specimens were etched in 60 mL of water, 10 g of NaOH and 5 g of $K_3Fe(CN)_6$ solution.
The X-rays diffraction analyses were accomplished in two diffractometers; one fitted with a back-reflection Laue camera. It was used a Cu tube and K_α radiation. The exposure time in the Laue camera was 7 h and 5 h, for alloy 1 and alloy 2, respectively. The working distance between the film and the sample was of 50 mm, for a power of 40 kW / 30 mA, for both specimens. The other used diffractometer was fitted with a scintillation detector, copper radiation was used at a power of 40 kW / 20 mA, 0.05 ° step scanning was undertaken (10 s analyses time for each point) and ranged from 95 ° to 5 °.

Results and Discussion

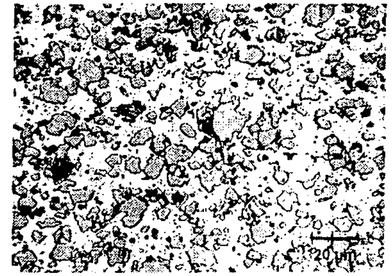
Table 1 shows the chemical composition of the two analysed hypereutectic Al-Si alloy specimens. Alloy 1 has a slight higher amount of Si than alloy 2 and it is not envisaged as a substantial chemical variation. The amount of Mg and Fe is similar in both alloys, whereas the Cu content in alloy 2 is much higher than in alloy 1. In both alloys, there are many alloying elements for the precipitation of fine phases and intermetallics, which may improve the mechanical strength and wear resistance.
For a better understanding of the results, it is presented optical and SEM micrographs of the two analysed alloys, where a homogeneous distribution of the silicon particles is observed (**Figure 1** and **2**). The chemical composition of these alloys presents silicon content well above the eutectic point. However, with a microstructure evenly distributed, free from segregation and without preferential orientation of the primary silicon and aluminium matrix, as it can be observed in the Laue photographs and on diffractometer traces seen on **Figures 3 to 6.**

Table 1: Chemical composition obtained by atomic absorption spectrophotometry for the materials used as cylinder liners (weight %). The gravimetric method was used to determine the Si content.

Material	Al	Si	Mg	Ni	Cu	Fe
Alloy 1	balance	23.19	1.00	0.96	2.70	0.19
Alloy 2	balance	20.76	1.10	0.01	4.00	0.21



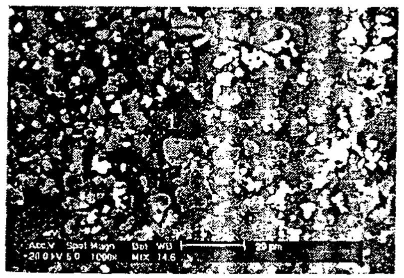
a)



b)

Figure 1. Optical micrographs of the spray formed alloys, where the homogeneity of the silicon particles is observed. **a)** Alloy 1. **b)** Alloy 2.

Figure 2 shows the obtained SEM micrographs of alloys 1 and 2, respectively. It is observed three different phases: dark phase, corresponding to the aluminium matrix (1), grey phase, corresponding to the primary silicon phase (2) and white intermetallics phase (3), mainly composed by $CuAl_2$. The phases have been identified by energy dispersive spectroscopy - EDS.



a)

b)

Figure 2. SEM micrographs of the spray formed alloys, showing three different phases: (1) aluminium matrix, (2) silicon particles and (3) intermetallics. **a)** Alloy 1. **b)** Alloy 2.
The figures 3 and 4 were obtained by X-rays diffraction in a Laue camera. It is noticed a similarity between the two alloys. There is homogeneity in both patterns, that it is typical of polycrystalline material. However, there is no texture definition. The illustrations 5 and 6 present the diffractometer traces of the Laue photographs. It can be observed that the two aluminium-silicon alloys present similar well-defined characteristic lines, besides a continuous radiation.

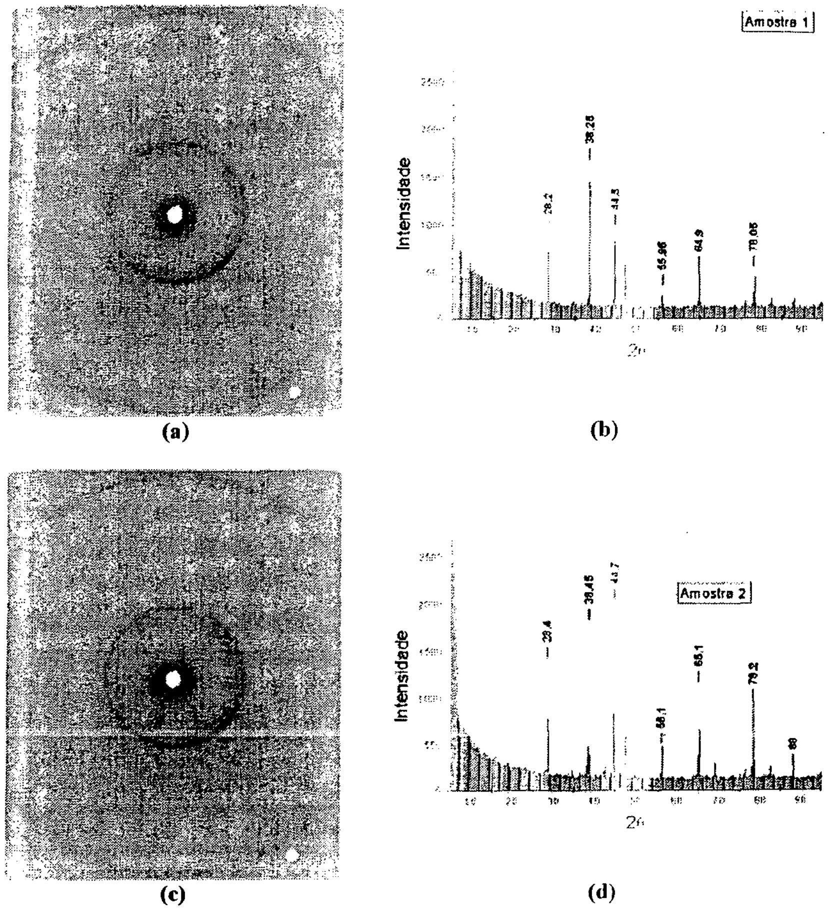


Figure 3. Back-reflection Laue photographs of spray formed aluminium-silicon alloys. **a)** Alloy 1. **c)** Alloy 2. Corresponding diffractometer traces obtained through measures accomplished in the Laue photographs **a)** and **c)**. Specimen-to-film distance 50 mm, copper radiation, 40 kV.

Conclusion

It can be stated that, in spite of: both cylinder liners come from different manufacturers; both alloys were spray formed hypereutectic aluminium-silicon material; both alloys have different chemical composition; both alloys probably undergone different thermo-mechanical treatments; both showed insignificant microestrutural differences as it can be seen from their micrographs and X-rays spectra.

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PREFACE

Since the genesis of the spray forming process – created by A.R.E. Singer during the 70s of the last millennium – more than 30 years have passed by – exactly the duration of a generation of man for growing up and becoming adult. Looking upon the spray forming process today one can recognize that a new technique like this among all the other established and partly competitive techniques also needs such a long period (or even more than 30 years) for coming into common use. Just like a rising generation is faced with enthusiastic phases and periods of hard learning as well as with first application of proficiency this also holds for the spray forming process.

While everything that is counted does not always count, we are convinced that it counts a lot to bring together the world wide growing (and also fluctuating) scientific community working on melt atomization and spray deposition. Offering a steady forum of interaction and feed back from the applicants to the scientists and vice versa, this is why the SDMA goes together with the ICSF, and we think this will stabilize and accelerate the evolution of this community as well as the progresses of the technique in various fields of application.

It also counts a lot to give time for ripening and for understanding the fundamentals that govern the process and the material properties. Therefore the scope of these interdisciplinary contributions after three years of ripening once again ranges from melt atomization, spray forming light metals and steels, thermal spraying, materials processing and process developments to diagnostic and control as well as modelling and simulation and also to post processing and special industrial applications.

As already in the year 2000, again it is a great pleasure for our Bremen group, to host the experts from all over the world in the frame of this conference. Spray deposition and melt atomization as well as the related disciplines are fields of growing research activities, technical importance and scientific fascination. In this context we would like to express our gratitude for delivering the keynote lectures to Prof. Dr.-Ing. Fr.-W. Bach, Dr. J.J. Dunkley and to Dr. P.S. Grant. We would like to thank the invited and contributing speakers for their excellent papers and also the scientific committee and the reviewers for their assistance and their valuable time and last but not least to the organizing committee.

And once again we have to thank the Deutsche Forschungsgemeinschaft (DFG), the industrial sponsors, and the University of Bremen for the financial support of this Conference.

Prof. Dr.-Ing. K. Bauckhage   Dr.-Ing. V. Uhlenwinkel   Dr.-Ing. J. Ziesenis

Bremen, April 2003

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